Robot Assistant in Management of Diabetes in Children Based on the Internet of Things

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***Abstract*—This paper presents a new eHealth platform incorporating humanoid robots to support an emerging multidimensional care approach for the treatment of diabetes. The architecture of the platform extends the Internet of Things to a Web-centric paradigm through utilizing existing Web standards to access and control objects of the physical layer. This incorporates capillary networks, each of which encompasses a set of medical sensors linked wirelessly to a humanoid robot linked (via the Internet) to a Web-centric disease management hub. This provides a set of services for both patients and their caregivers that support the full continuum of the multidimensional care approach of diabetes. The platform's software architecture pattern enables the development of various applications without knowing low-level details of the platform. This is achieved through unifying the access interface and mechanism of handling service requests through a layered approach based on object virtualization and automatic service delivery. A fully functional prototype is developed, and its end-to-end functionality and acceptability are tested successfully through a clinician-led pilot study, providing evidence that both patients and caregivers are receptive to the introduction of the proposed platform.**

***Index Terms*—Diabetes, eHealth, Internet of Things (IoT), multidimensional care, object virtualization, robot-assisted therapy.**

I. Introduction

PREVALENCE of diabetes is increasing at an alarming rate worldwide. It is estimated that 415 million people have diabetes, every 6 s a person dies from diabetes with the accounts for 12% of the global healthcare expenditure [1]. As a result, there has been an increased pressure on the available healthcare resources, and patients diagnosed with diabetes require a more efficient and individualized disease management plan to prevent (or delay) progression and treatment costs of the short- and long-term complications of the disease.

Benefiting from technology advancements and cost reduction in wireless networks and Web technologies, numerous electronic/mobile health (e/mHealth) applications [2]–[4] have been increasingly reported in the literature. These applications offered various levels of user interaction intensity; ranging from general information, specific information targeting specific patients, to tailored user feedback information. Authors of these studies generally agree that ICT solutions are effective in diabetes management in terms of patient monitoring and technology-based decision support applications but further studies are still needed to assess the effectiveness of technology-based solutions with respect to long-term behavior change support in self-management, adherence and patient engagement with their health carers. In addition, most of these solutions are focused on the functionality, technological and mobility issues but not on behavioral changes and acceptability challenges of these applications. Continued improvement in diabetes self-management and, in particular, type 1 diabetes mellitus (T1DM) in children and adolescents therefore requires a multidimensional care approach that is not only focused on routine diabetes care activities but also on psychological and social dimensions.

The multidimensional care approach of diabetes has emerged in 2010 [5], when a multidisciplinary team combined psychological and social aspects with the traditional primary care of diabetes. Preliminary findings from a clinical trial showed a significant improvement in the blood sugar control in those who engaged in this care approach [6]. However, the requirement of engaging additional physicians is likely to be financially unsustainable in the current frugal economic climate in light of NHS staffing constraints. This is where the incorporation of eHealth technologies to facilitate the seamless and asynchronous interaction between the patients and their caregivers could potentially add a significant value by improving both efficiency and productivity of the care process, while providing a personalized and patient-centered experience.

The Internet of Things (IoT) is a new concept associated with the future architecture of applications development in which the physical objects (POs) and virtual (or digital) objects (VOs) are interconnected through various means to enable new application and services [7]–[9]. The VOs tend to be smarter representations of the POs through enriching their digital models by cognitive management functions and user information [10]. They also can have several attributes in common [11]. However, based on practical experimentation and prototyping, these objects can be categorized into three types: 1) activity-aware; 2) policy-aware; and 3) process-aware objects. The key differences between these object-types can be identified in terms of awareness, representation, and interaction [11]–[13].

The work presented in this paper suggests a next generation of eHealth platform driven by the requirements of the

Manuscript received December 1, 2015; revised May 28, 2016 and July 11, 2016; accepted October 24, 2016. Date of publication November 1, 2016; date of current version April 28, 2017. This work was supported in part by the 7th European Community Framework Programme, under Grant 275571, and in part by Kingston University London, U.K.

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Digital Object Identifier 10.1109/JIOT.2016.2623767

multidimensional approach of diabetes care and the IoT architectures. It suggests a novel technology support that integrates diverse diabetes care aspects, robotic coaching, wireless technologies, and distributed intelligence in a single platform. Incorporation of robots in diabetes management, which is not yet thoroughly explored in literature improves patient-carer interactions over a distance and allows for a more efficient and cost-effective implementation of the multidimensional care approach. In the proposed application scenario, the platform is based on policy-aware IoT objects with the following design dimensions.

1) *Awareness:* Understands to what extent the patients' activities comply with their individual treatment plans.
2) *Representation:* Applies a set of rules on patients' data streams and extracts useful summaries and health indicators such as blood glucose (BG) patterns, insulin bolus calculation, and patients' categorization depending on attributes of their health conditions.
3) *Interaction:* Uses accumulated data stored in the patient's electronic medical record to create reminders, warnings messages, and appropriate health advices when self-management outcome deviates from prespecified targets.

The remainder of this paper is organized as follows. Section II describes the distributed architecture of platform and its software design pattern. Section III describes the disease management hub (DMH) interfaces, and service creation and management. Next, the main applications of the robot and DMH are described in Section IV. Aspects of the platform support to diabetes management are presented and discussed in Section V along with some results obtained from a pilot clinical acceptability study. Finally, this paper is concluded in Section VI.

II. Distributed Architecture

The scenario adopted in this paper is an eHealth platform with remote accessibility and manageability of variety of POs. Network architecture of the platform encompasses two main components: 1) capillary networks of the POs and 2) a Web-centric DMH for patients monitoring and disease management. The long-range connectivity between these components is performed through a wireless local area network (Wi-Fi) linked to an existing network infrastructure (the Internet) as illustrated in Fig. 1. Each capillary network comprises a set of medical sensors (BG monitor, blood pressure and pulse rate monitor, and weight scale), and an existing humanoid robot [14].

The medical sensors are linked to the robot through a personal area network in which the robot acts as a master Bluetooth device, as illustrated. The robot at each capillary network also acts as a conduit between the patient and his/her medical sensors from one side and the DMH and caregivers from the other side. The DMH provides a set of services that cover the full continuum of diabetes management for the patients and their caregivers.

VOs of the DMH are capable of interpreting events and activities with respect to predefined healthcare policies/guidelines in terms of awareness, representation and interaction. For instance, these objects understand to what extent the patient's activities comply with the treatment plan/guidelines, apply rules on patient's data streams to extract useful summaries, and use accumulated data to create appropriate warning messages and advices to the corresponding objects at the physical layer.

Fig. 1. Abstract view of the proposed eHealth system.

A. Software Architecture

Software development of the main platform components (i.e., the robot and DMH) is unified and logically divided into three main components: 1) system; 2) database; and 3) applications. The components are shown in Fig. 2 and are described briefly as follows.

1) *System:* Refers to the core classes, configurations and service libraries that provide a skeleton and a container for various applications at both the robot and the DMH.
2) *Database:* Represents both local and centralized storage for the robots of the capillary networks and the DMH, respectively.
3) *Applications:* Refer to the modules that handle PO-related functionalities including human objects.

Design of all application modules at both the robots and the remote DMH are compliant with the model-view-control (MVC) architectural pattern that provides a practical solution to separate the user interface (view) from the data (model). In this pattern, the view interacts with the model through the controller that mediates the input and converts it to commands for the model or view.

This logical division of the applications development improves interlayer operability, software reusability and maintainability across the platform [7]. It also enables the developers of IoT applications to develop various applications without the need to know low-level details of the platform.

B. Object Virtualization

Virtualization of the POs is a key requirement for IoT infrastructure. It enables digital representation of objects and acts as an interpreter between the physical and the virtual layers of the platform. A layered object-virtualization approach [15], [16] is adapted in this paper to ensure interoperability and reusability of VOs. A two-stage virtualization process is carried

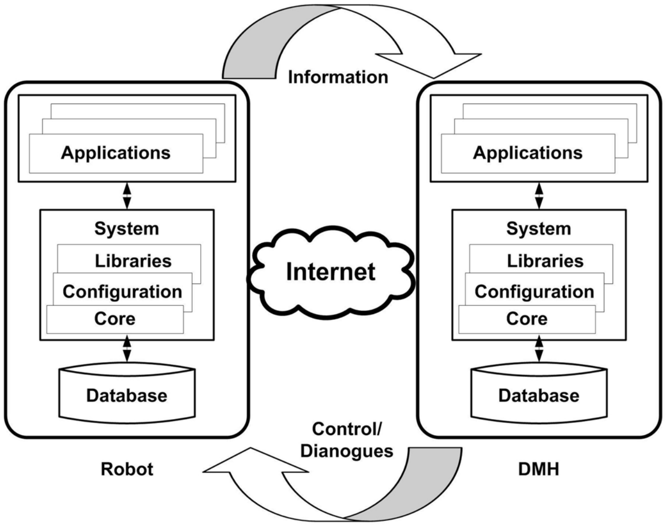

Fig. 2. Software architecture of the eHealth system.

out at the robot and the remote DMH to provide digital representation for all PO of the proposed platform.

1) Robot's Virtualization: The robot virtualizes all real-world (or physical) objects in the associated capillary network (i.e., the patient and his/her medical sensors). The VOs provide semantic descriptions for the associated POs using a unified structure for both the device and human objects. This enables efficient data exchange between different types of objects through specifying the data and its relationship among other objects. As a result, the POs can be accessed through their VOs, which in turn act as translators between the digital and physical worlds.

2) DMH's Virtualization: The DMH virtualizes the robot objects of different capillary networks as well as other user objects (i.e., caregivers and technical support staff) are virtualized at this stage. Unlike the robot virtualization where each VO is constrained by the capability of the associated PO, more complex VOs, called composite VOs (CVOs) are required at this stage to represent the case, where multiple VOs collaborate to accomplish a particular task. For example, the physician VO needs to collaborate with the medical sensor VOs to create and deliver a warning message/advice to the patient when the disease management outcome deviates from a prespecified target. Semantic features of such a CVO describe its capabilities and relationships with other objects and thus help locating suitable objects that can respond to a certain service request.

III. Robot Applications

Application modules of the robot are devoted to handle all day-to-day interactions with the patient and his/her medical sensors from one side and the DMH from the other. An application manager, as shown in Fig. 3, performs execution, coordination and management of these modules. Except for the dialogue management module that is developed using python language, all other modules are developed using C++ language. The specific roles performed by each of these application modules are described briefly as follows.

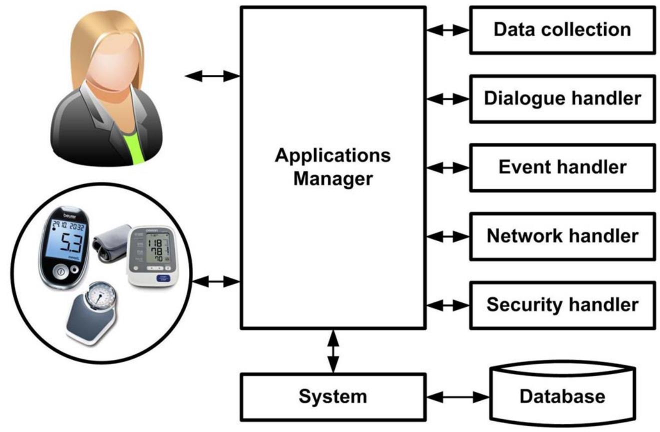

Fig. 3. Application modules of the robot.

A. Data Collection

It initializes Bluetooth connectivity between the robot and medical sensors and collects the relevant measurements. It manages and synchronizes data collection between the robot and each of the associated medical sensors through generation of several handshaking messages (i.e., ready, data received, and waiting timeout).

B. Dialogue Handler

It performs all kinds of verbal robot–patient interactions. It allows for collection of verbal information concerning the patient's diet, insulin bolus intake, and physical exercise as well as recording patient's video/audio messages to his/her caregivers. It also manages presentation of various dialogues assigned to the patient by his/her physician. These interactions are accompanied by appropriate emotion signs (e.g., happy, sad, excited, etc.) to enrich the interaction by making it more natural.

C. Event Handler

It manages various tasks relevant to robot interactions with the patient and his/her medical sensors. Based on the type and source of interaction, this module initializes the robot's behavior and dispatches the interaction attributes to other relevant modules. This module plays a key role in synchronizing the execution of parallel tasks and ensures execution of sequential tasks by a correct order. It also notifies the application manager on the start/completion status of various tasks.

D. Network Handler

It represents a gateway for the entire robot applications with the remote health portal. It performs network connectivity with the remote health portal by means of HTTP request/response mechanisms.

E. Security Handler

It handles the encryption and decryption process for all kinds of data exchanged between the robot and the DMH.

F. Database

It is an abstraction for a local robot database that provides simple functions to all database tables to insert, delete, update, and select data. The database is used to store interaction data temporarily. Interaction data refers to all information gathered either from patient's medical sensors or verbally and the information retrieved from the health portal, such as dialogues and treatment plan thresholds.

IV. DMH Interfaces and Applications

A. DMH Interfaces

Service requests of the physical-layer robots and human users of the platform are handled by various applications hosted by the DMH. The DMH is accessed through two different interfaces for human and device objects.

1) Human–Object Interface: It provides access interface for different human objects (i.e., physicians, nurses, dieticians, informal care givers, and patients) through Web browsers. This of interface supports accessibility of system users depending on preassigned role and access permissions granted to each user. The request/response sessions between the users and the DMH are processed securely through utilizing secure HTTP (HTTPS) protocol that provides the necessary authentication and thus security of the exchanged data are protected.

2) Device–Object Interface: Unlike the human–object interface, the HTTPS is not available for the device objects. Instead, the unsecure HTTP can be utilized to process the request/response sessions between the physical-layer robots and the DMH. In the proposed platform, the robots exchange data with the DMH through periodic data synchronization between local databases of the robots and the central database hosted by the DMH. No HTTP requests are expected from the DMH end; thus the robot is protected from external access.

B. DMH Applications

Human and device objects of the physical layer can access applications of the DMH through a unified access interface mechanism. As explained earlier, the software architecture of this hub follows the MVC pattern in which the controller and view of all applications are represented by a core functionality module called service request manager, as shown in Fig. 4. The controller handles all business logic processes, including virtualization of POs, interactions between VOs, and performs all tasks relevant to service creation and management. It also acts as a coordinator between the models and views for nonasynchronous JavaScript and XML (AJAX) requests (i.e., first page loading) of the browser-based interface. All subsequent AJAX requests are handled by the unified access interface. This saves processing time, minimizes page-loading time, and thus improves the user-machine interactivity.

The view is a set of HTML templates that are used to monitor patients' health profiles in various tabular and graphical charts. The model is created for each object entity registered in the central database and used to provide CRUD (create, read, update, and delete) functionality to active entities. Before describing the service request manager, the main DMH applications are described briefly as follows.

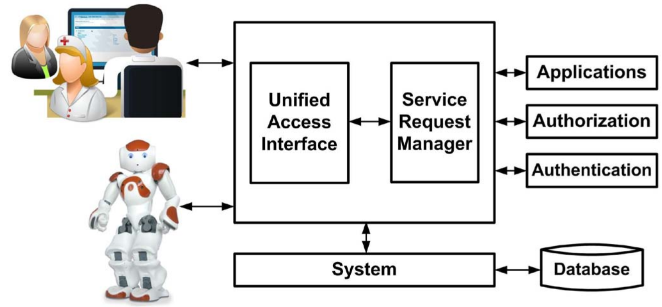

Fig. 4. Software architecture of the DMH.

1) Device Registration and Management: It allows new users to register their robots medical devices using unique IDs (e.g., serial numbers) as well as a security token that is randomly generated by the robot upon its first use. The device ID and security token number are used to encrypt and decrypt data exchanged between the robot and DMH. The patient, as necessary, can then maintain his/her profile. Once registered, the patient will then be assigned to a professional caregiver, depending on his/her health status.

2) Dashboard: It represents a single-page summary for the patient and the caregivers. It also provides access links to all key platform applications, such as treatment plan, diabetes diary, BG patterns, and other applications. For the patient, it summarizes the health profile through monitoring patient's vitals and trends of bio-data, pediatric summary, medical summary, and most recent laboratory tests. For the caregivers, it displays patient's icons that are hyperlinked to the corresponding patient dashboard. These icons are colored red, yellow and green to reflect good, acceptable and poor disease management performance. This saves time and helps the caregivers prioritizing their efforts accordingly.

3) Diabetes Diary: It provides a more detailed record for the day-to-day measurements and information collected from the patient, including the amount of carbohydrate intake, physical exercise, well being index, etc. These data are processed and presented in several different ways (tabular, pi-chart, and histogram).

4) Treatment-Plan Setting and Dialogue Assignment: It serves two main purposes: 1) building a treatment strategy and goals set up and 2) assigning empowerment (i.e., education and motivation) dialogues to the patients. Several key parameters that affect the entire disease management process are set up through this application; of these the following are the most important.

1) BG target settings that specify custom targets upon which the day-to-day BG measurements are categorized as within-, above-, or below-targets.
2) Dose of the background insulin that is typically taken by the patient daily or every 12 h, depending on the type and activity period of insulin.
3) Thresholds of BG patterns that specify the frequency of consecutive BG measurements that are above or below targets BG pattern. The decision support module uses these thresholds to identify various types of BG patterns.

4) Insulin sensitivity settings that are required by the decision support module to calculate the insulin bolus for each meal or snack.

5) Decision Support: Patients living with diabetes are not constantly watched, like in a clinic or a hospital, but are managing their disease largely by themselves. Therefore, patients need to make the best-individualized care decisions about daily management of their diabetes. For example, accurate calculation of the insulin bolus per meal or snack is crucial for patients with T1DM to maintain their blood sugar levels within the acceptable range [17]. In traditional care, the parents are often called to help their children. In the proposed system, the robot offers decision support not only in calculating the insulin bolus but also in provision of real-time feedback, summarizing the BG readings over the past 24 h and how they differ from the trend of the previously collected readings. In addition, the system also provides (via the robot) details on the recognized BG patterns [18] along with appropriate advices that are generated depending on both the current and historical data stored in the patient's medical record. This kind of support is automatically created by DMH and delivered to the patient (via the robot) in real-time without direct intervention from the professional caregivers. On the other hand, the system also supports the caregivers through generating a compliance index for each patient [19]. This improves patients' follow up and help prioritizing delivery of healthcare services based on their compliance index, especially in situations where available caregivers are insufficient to meet the care demand.

6) Dialogue Creation Wizard: In order to improve engagement of the patients with their caregivers, a user-friendly dialogue creation wizard was developed [20] to support creation and delivery of various kinds of dialogues to the patient's robot at home. This wizard allows building various types of dialogues using drag-and-drop mechanism and node connections tool. Each dialogue consists of a number of nodes, each of which represents a single step in the interaction and performs one of the following tasks.

1) *Decision Making:* Sets a navigation path depending on the user's response.
2) *Information Reporting:* Provides the patient with personalized feedback relevant to the disease management.
3) *Information Collection:* Collects patient's information, such as diet, exercise, medications, wellbeing, etc.
4) *Message Collection:* Collects patient's views in terms of short audio/video messages.

V. Interactions and Service Request Management

A. Objects Interactions

The platform is driven by the technology support needs of an emerging multidimensional care approach for diabetes. As explained in Section IV, the developed platform offers various technology support means for this care approach, including remote patient monitoring, decision support, and long-term behavioral change support through delivery of various patient empowerment modules. There are numerous useful models on behavior change, of these; the information-motivation-strategy model is the most outstanding [21]. Different strategies were also suggested in [22] and [23] for patients' empowerment through improving engagement with their caregivers to help them cope with challenges of diabetes management in everyday life. This platform offers the tools necessary to fulfill this need over a distance and thus avoiding the place and time restrictions of the face-to-face clinic visits. The new care cycle scenarios of platform support to diabetes management are shown in Fig. 5 and the relevant interactions between different objects are summarized in Table I.

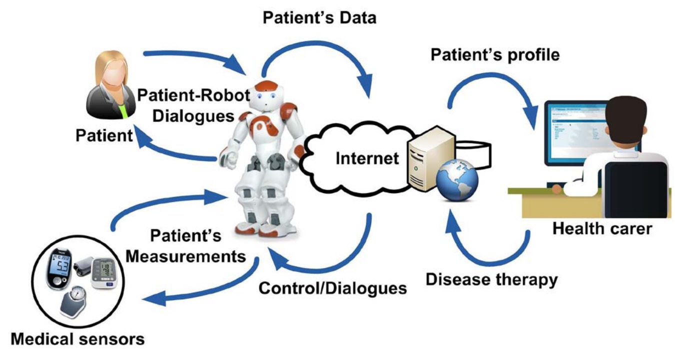

Fig. 5. Care cycle and scenarios of system support to diabetes care.

TABLE I
INTERACTIONS OF PLATFORM OBJECTS

Interaction	Description
Medical Sensors/Robot	Collection of BG, blood pressure, pulse rate, and body weight measurements.
Patient/Robot	Collection of carbohydrates intake, basal and quick-acting insulin boluses, physical exercise level, illness conditions (if any), well-being, and patient's views/messages to his/her health care professionals.
Robot/DMH Server	Pre-process and upload the collected data to the remote health portal server.
DMH Server / Robot/ Patient	Real-time system-generated feedback to the patient (health profile summary, blood glucose patterns with relevant health advices/warnings, and the required insulin bolus per meal/snack).
Caregiver/ DMH Server	Periodic review of patient's health profile, adjust therapy plan (if necessary), build/assign dialogues for patients education and long-term behavioral change support.
DMH Server/ Caregiver	Notification for patients with poor disease management performance.
DMH Server / Robot/ Patient	Periodic caregiver's feedback to the patient (new/amended therapy plan, education/motivation dialogues, well-being assessment, and health advices).

B. Service Request Management

The main functionality of the DMH is performed by application, each of which has a specific authorization level. All applications follow a similar design pattern such that they can be accessed using a unified interface. Management of services are dependent on: 1) type of the requesting object (i.e., device or human user); 2) user profile (i.e., patient, caregiver, support staff, etc.); and 3) context of the service request (i.e., internally or externally initiated). For example, some service creation requests are initiated internally by the DMH when the outcome of the disease management process deviates from prespecified

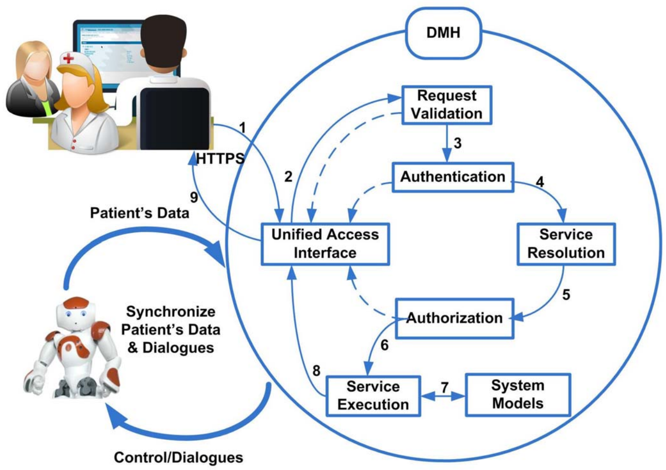

Fig. 6. Service request management.

targets. Once these parameters are identified, the related models are invoked to grant access to the central database. The main units involved in handling a service request are explained with the aid of Fig. 6, as follows.

1) Application Access Interface: It represents an entry point for all service requests coming from the physical-layer objects. It unifies the access mechanism to DMH applications and thus it further improves security, software reusability and maintenance of the platform and the DMH in particular.

2) Request Validation: It validates incoming requests depending on attributes of the requested service.

3) Authentication: It authenticates incoming requests using HTTPS session/cookies or the access keys that are provided as part of the request payload.

4) Service Resolution: It creates an instance of the requested service and passes it to the authorization unit along with the request payload.

5) Authorization: It ensures that the authenticated object (user or robot) is authorized to access the requested service.

6) Service Execution: It invokes the requested service logic, and sends back the request's payload to the service access interface.

The dataflow between these units can be summarized as follows: upon receiving a certain request, the service access interface sends it to a request validation unit. If it is found to be a valid request, it proceeds to an authentication module; otherwise, if the request is found to be invalid, it is dropped and the service access interface is notified to reject the request. Next, depending on the source of the request, the authentication unit either uses an HTTPS session-based for browser-based requests (user clients) or a key-based authentication for nonbrowser-based requests (i.e., device clients).

If the authentication was unsuccessful, the service access interface is notified to reject the request. Otherwise, the request is passed to the service resolution unit, which instantiates the requested service and passes it to the authorization unit along with the payload. Next, the authorization unit grants the authenticated user access to the requested service. Authorized access will then be forwarded to the service execution unit that first passes the payload to the requested service object, invokes the requested service, and then sends back the execution results to the requester via the service access interface.

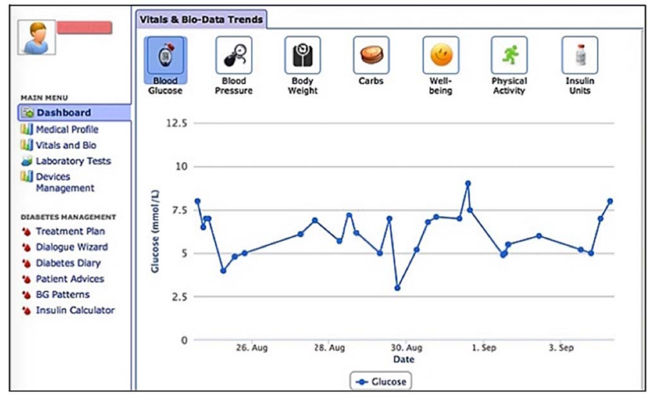

Fig. 7. Sample screenshot of the DMH dashboard.

VI. Results and Discussion

Numerous test scenarios have been carried out to assess data quality (DQ) and end-to-end functionality and a seamless, secure and accurate data exchange has been demonstrated between different layers of the platform. In this section, some key aspects of the developed eHealth platform are presented and discussed.

A. Patient Monitoring

A sample screenshot for the DMH dashboard that provides a single-page summary for patient's health profile is depicted in Fig. 7. It also provides access links to all key platform applications, such as treatment plan, dialogue wizard, diabetes diary, BG patterns, and other applications, as illustrated. The primary design goals, which included the automaticity of remote data collection, monitoring of patients data, and maintaining continuous interactivity between the patients and their health carers have been accomplished. It was also demonstrated that the platform understands to what extent the patients comply with their individual treatment plans. DMH's ability to extract various BG patterns and generate appropriate feedback to patients when their health conditions deviate from specified targets has also been demonstrated successfully.

B. Patient–Robot Interaction

Patient–robot dialogues support patients' empowerment and motivation toward healthy lifestyle and improved BG control. These dialogues are created by specialist clinicians and saved into a dialogue library at the DMH that is made accessible to all caregivers. The dialogues in this library can be assigned to patients as required, depending on their individual needs to support the disease management process.

Once assigned by the physician, the dialogue is automatically sent to the robot at home which in turn performs the specified interaction with the patient. For example, the robot reports any changes made in the treatment and the identified BG patterns over a certain period of time. Next, the dialogue may proceed to collect patient's information/messages

Fig. 8. Example of a patient–robot interaction setup.

relevant to diabetes management. During the dialogue execution, the robot may also communicate with the DMH server to exchange data/messages between the local and remote database. Example of the patient–robot interaction setup is shown in Fig. 8.

C. Data Quality

DQ has been described in the literature with multiple dimensions. However, there is no consensus on a rigorously defined set of dimensions [24]. In the developed platform, the DQ is facilitated by: 1) accurate identification of the patients and their devices; 2) implementation of health-related DQ dimensions (i.e., accuracy, completeness, consistency, timeline, and usability); and 3) data transmission integrity. Implementation of these mechanisms is described briefly as follows.

1) Patient/Device Identification: This mechanism is performed at both the local capillary network and the remote DMH. At the local network, the robot identifies the patient either through a face recognition facility in the robot or by identifying a key that is randomly generated by the robot upon its first use. Upon successful identification, the robot starts interacting with the patient and enables Bluetooth connectivity with the medical devices. Similarly, the robot attempts to establish a connection with the remote DMH using the same key subject to its preregistration at the patient's profile. If successful, the DMH server returns a unique identifier (ID) for the robot that is used in all future communications across the platform layers. This ensures that the patients' profiles match the patients by cross-layer IDs.

2) Health-Related DQ Dimensions: Once the data collection process completes, the robot summarizes the collected data to the patient to verify: 1) its conformity with the actual readings of the medical devices (i.e., accuracy); 2) none of the anticipated data is missing (i.e., completeness); and 3) the collected measurements are consistent with the actual readings of the medical devices (i.e., consistency), and to obtain verbal consent prior to sending them to the remote DMH. At the DMH, the data elements that do not match the patient's health profile or historical data are filtered by presetting certain threshold for each data source beyond which the data is considered abnormal. Each of the data elements is also time-stamped to enable its storage in a chronological order to facilitate its availability on time.

3) Data Transmission Integrity: It guards against improper data modification or destruction while in transit. This dimension was implemented within a comprehensive security solution [25] that embeds various security dimensions including data transmission integrity into software development lifecycle of the platform. The periodic synchronization between the central DMH database and local databases of the robots is secured through developing and implementing a cryptography method that does not include full authentication data in the transmitted packets between the two ends. Instead, it distributes the authentication data between three different entities: 1) the user; 2) robot; and 3) the DMH server, and thus maintaining robust communication channel security against improper data modification or destruction.

These DQ mechanisms were validated through conducting intensive end-to-end experimental tests that were carried out jointly with the patients and their health care professionals through a pilot clinical acceptability study.

D. Acceptability

A pilot clinical acceptability study was conducted with the aim of exploring how young diabetics and their caregivers receive the proposed platform. This paper also aimed to determine how the patients feel the robot, as a new medical device, may contribute to their care, and how they respond to the advices and education provided by the robot. This paper also investigated how the robot serves as a communication device between patients and health care professionals. A total of 22 patients equally divided between males and females (8–15 years old) with T1DM and seven clinicians (four diabetes consultants, a nurse, a dietitian, and a diabetes technician) participated in this paper. Acceptability of the platform was measured in terms of the following four specific services (S1–S4) that were considered of interest to both the patients and their caregivers.

The obtained results showed a relatively high acceptability level, as shown in Fig. 9. These results as well as the positive comments received from the patients and their parents have been promising. A wider and more detailed study of the feasibility and acceptability of the platform are recently reported by Al-Taee *et al.* [26], [27]. Unlike other existing e/mHealth platforms, which are mostly focusing on mobility and remote patient monitoring, design and architecture of the proposed platform is driven by several key emergent healthcare requirements and technology developments.

1) It supports multidimensional care approach that integrates social and psychological care with the traditional primary care of diabetes in a single platform without imposing financial burden on the NHS budget.
2) It responds to the growing need to conduct social and behavioral studies to address adaptability challenges of diabetics with their health carers and families.

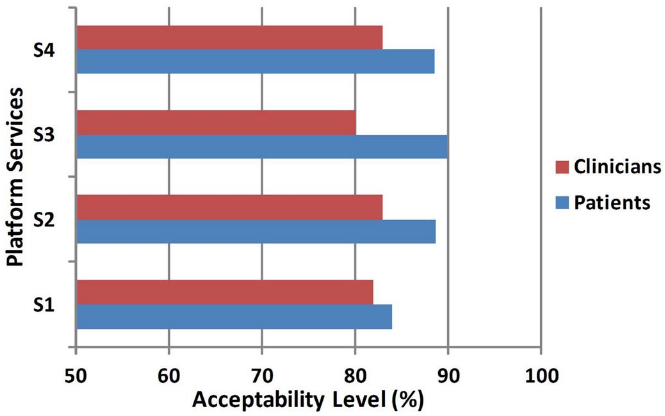

Fig. 9. Patients and clinician acceptability of the eHealth system. S1 relay audio/video messages from patients to their health care professional. S2 provide patients with education modules about diabetes at home. S3 recognize patterns of hypo/hyperglycemia and advice the patients accordingly in real time. S4 relay BG readings from patient's monitors at home.

3) It is based on the IoT architecture that can addresses the challenges of developing the next generation of a personalized delivery of healthcare services and potentially reshape some of the current healthcare delivery systems and relevant services.

Developing such an innovative platform is expected to dramatically improve diabetes care through: 1) supporting long-term behavioral change from unhealthy to healthy lifestyles; 2) delivery of cost-effective healthcare services over a distance; and more importantly 3) improving BG control in children and young adults.

VII. Conclusion

A fully functional IoT-based eHealth platform that incorporates humanoid robot assistance in diabetes management in children has been designed and developed successfully. This is achieved through an intelligent, adaptable and reconfigurable process of participatory design in which patients are heavily involved in creating their personalized health profile, follow-up and treatment plans. The developed platform facilitates a continuous but loosely coupled connectivity between patients and their caregivers over a distance and thus improving patients' engagement with their caregivers and minimize the cost, time, and effort of the traditional periodic clinic visits. This will also contribute to long-term behavioral change from unhealthy to healthy lifestyles.

The end-to-end functionality and DQ of the developed platform were tested through a pilot clinical acceptability study. The suggested architecture and applications can also be considered a blueprint for developing a generic eHealth platform for management of various chronic diseases other than diabetes. This platform is therefore remains open for further technical improvements and clinical studies. In particular, the virtualization approach and semantic representation of POs that tackles the heterogeneity challenge of the platform can be further improved through enhancing the cognitive capabilities of the VOs. This approach can be adopted to realize a more flexible patient–robot dialogues. Further clinical studies are also required to assess the impact of the proposed technology on the quality-of-life of young diabetics. The implemented mechanisms for DQ can also be further improved by using an advanced patient-profile matching through probabilistic algorithms, as needed.

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